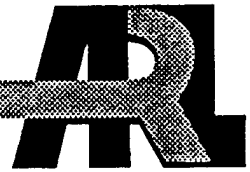


ARMY RESEARCH LABORATORY



A Particle Rendering System For Displaying Cloud Liquid Water Content Data

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By
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**Information Science and Technology Directorate
Battlefield Environment Division**

ARL-TR-552

July 1997

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A means for graphically displaying cloud liquid water content data is described in terms of both theory and C language code. Given the appropriate parametric equations and graphics display enhancement techniques (dithering and jittering), the graphic display can be fairly easily achieved when built around a library of graphic routines such as Sun Computer's XView.

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Preface

This report is the culmination of an independent study project undertaken in May 1994, while the author was participating in long-term training at the Computer Science Department of New Mexico State University, under the sponsorship of the U.S. Army Research Laboratory. As no upper division computer science courses were offered for the first summer session, it was decided an independent study project would be appropriate. In light of the fact that the author had already taken a graphics course at New Mexico State University and had worked in the area of meteorology, this project was a natural combination of disciplines.

The methods used for this effort were originally discussed in the paper, "Stereo Animation for Very Large Data Bases: Case Study-Meteorology," by Thomas Papathomas and others from the *Institute of Electrical and Electronics Engineer's Journal*, September 1987.

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Executive Summary

Introduction

A data file from the Experiment on Rapidly Intensifying Cyclones over the Atlantic (ERICA) was obtained and graphically rendered on a Sun workstation using the framework of a particle rendering system. The mathematics behind the rendering is discussed by deriving the required parametric equations. Techniques for enhancing the graphical display of the cloud liquid water content, such as dithering and jittering, are described as well. The pseudocode for rendering is also given, illustrating the use of the parametric equations and the enhancement techniques.

Purpose

The goal of this effort, was to write C language software which would depict, as realistically as possible, a cloud image from cloud liquid water content data on a UNIX workstation such as a Sun or a Hewlett-Packard.

Overview

A literature search was first carried out to determine what work had been done in the area of particle systems. Particle systems have been used to model entities such as fire, clouds, and water. A dramatic example of their use is in the movie, *Star Trek II: The Wrath of Khan*, in which fire and explosions are very realistically simulated. [4] Reeves uses stochastic processes to generate particles in a particular volume and assigns initial velocities to each particle. These concepts were considered until the author found that clouds could be rendered using simpler means through the use of perspective projection equations only. [3]

In the particle rendering system, each point is considered as a light source, and where the point projects onto the screen is a function of the data point coordinates as well as the chosen coordinates of the eye. Both random jitter and dithering are applied to the projected points. [3] The application of random jitter eliminates the lattice effect one sees when the gridded data points are rendered without any massaging. Dithering provides the viewer with a sense of magnitude at each

point. This is accomplished by applying a dithering matrix, in this case a 3 x 3 matrix, at each point; whereby, the number of pixels turned on within that matrix will be proportional to the magnitude of the data value at that point.

Conclusions

A three-dimensional rendering of cloud liquid water content can be done fairly simply on a UNIX platform, such as Sun, with the appropriate parametric equations and rendering techniques and using the display capability of the XView library of routines provided by Sun Computer.

Recommendations

For the requirement of a static display of cloud liquid water content using Sun's XView library of routines, the techniques described herein should prove to be quite useful.

1. Introduction

1.1 Background

A technique is given for displaying cloud liquid water content data in three dimensions. The data file from the Experiment on Rapidly Intensifying Cyclones over the Atlantic (ERICA) was output from the Limited Area and Mesoscale Prediction System (LAMPS), developed at Drexel University, which produces a three-dimensional grid of the original data set. In a particle rendering system, each point within a three-dimensional data set is projected onto the x-y plane (computer screen) using the perspective projection equations. The rendering software is written in C and uses the XView library of graphic routines from Sun.

1.2 Purpose

The purpose of this report is to describe a relatively simple technique for three-dimensional display of cloud liquid water content. Using Sun's XView library of routines, this technique is easily implemented.

As this was an independent study project, the author's advisor clearly stipulated that commercial rendering software packages not be used, but rather the code should be "built from the ground up." The effort began in May 1994 when the author registered for an independent study project which concludes with this documentation.

1.3 Overview

First, the ERICA data set is described including how it was created and its dimensions. Next, the techniques used in a particle rendering system are analyzed including the perspective projection equations, as well as dithering and jittering. The Results section (2.3) shows the graphical display of cloud liquid water content with the particular parameters used to achieve the image. Lastly, the graphical display software is outlined in terms of pseudocode.

2. Cloud Particle Rendering System

2.1 Cloud Liquid Water Content Data

2.1.2 *ERICA Data Set*

The data set used for this project is an $83 \times 53 \times 34$ (x, y, z) grid of cloud liquid water content. The original data set of cloud liquid water content comes from the ERICA experiment, and the grid is output from the atmospheric dynamics software module called the LAMPS, developed at Drexel University. The areal extent of the grid is from 99.658° to 34.938° West longitude and from 22° to 54.5° North latitude. The layers in the vertical are at the surface, .025 km, .375 km, .75 km, then every 0.5 km up to 15.25 km, with the top layer at 16 km.

2.2 Techniques

2.2.1 *The Perspective Projection Equations*

The perspective projection equations allow one to project points from x, y, z space onto the computer screen. [1]

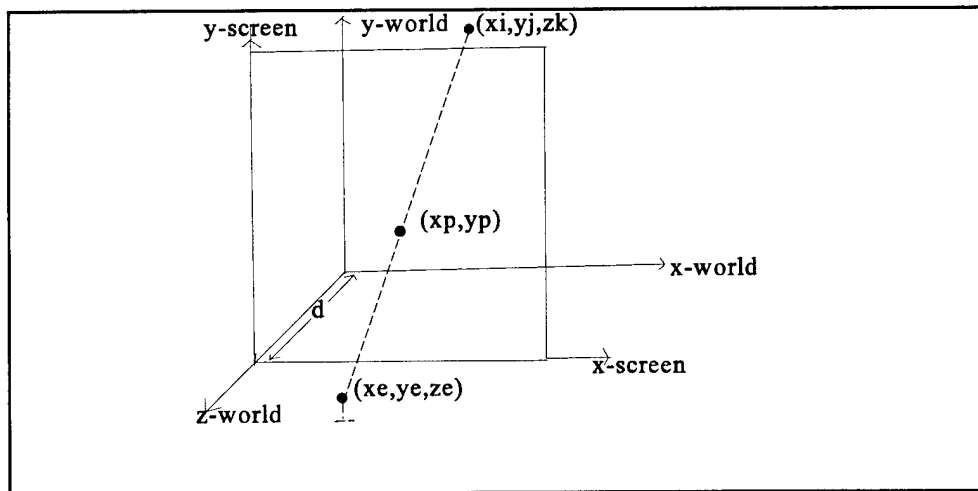


Figure 1. Graphical depiction of world and screen coordinate system, eye position (x_e, y_e, z_e) and a projected point (x_p, y_p).

The equations are derived as follows:

x-screen = x-axis of computer screen.

y-screen = y-axis of computer screen.

x-world = x-axis for liquid water content data set.

y-world = y-axis for liquid water content data set.

z-world = z-axis for liquid water content data set.

d = distance between the planes formed by x-world, y-world and the screen.

xi = x-coordinate of liquid water content data set.

yj = y-coordinate of liquid water content data set.

zk = z-coordinate of liquid water content data set.

xe = x-coordinate for the viewer's eye.

ye = y-coordinate for the eye.

ze = z-coordinate for the eye.

xp = x-coordinate of the projected point on the computer screen.

yp = y-coordinate of the projected point.

zp = z-coordinate of the projected point.

$$x_p = x_e + p * (x_i - x_e) \quad (1)$$

$$y_p = y_e + p * (y_j - y_e) \quad (2)$$

$$z_p = z_e + p * (z_k - z_e) \quad (3)$$

$$d = z_e + p * (z_k - z_e) \quad (4)$$

The equations above represent the parametric equations for projecting the x,y,z point in the liquid water content data set onto the computer screen.

On a line formed by the points (xe, ye, ze) and (xi, yj, zk) p represents the fractional distance that (xp, yp) is from (xe, ye, ze).

As you can see, we have let $d = z_p$
At $d = 0$,

$$p = -\frac{z_e}{(z_k - z_e)} \quad (5)$$

so,

$$x_p = x_e + \frac{-z_e}{z_k - z_e} * (x_i - x_e) \quad (6)$$

$$= x_e + \frac{x_e * z_e - x_i * z_e}{z_k - z_e} \quad (7)$$

$$\frac{x_e * z_k - x_e * z_e - x_i * z_e + x_e * z_e}{z_k - z_e} \quad (8)$$

$$= \frac{x_e * z_k - x_i * z_e}{z_k - z_e} \quad (9)$$

Similarly in the y-direction,

$$y_p = y_e + \frac{-z_e}{z_k - z_e} * (y_j - y_e) \quad (10)$$

$$= y_e + \frac{y_e * z_e - y_j * z_e}{z_k - z_e} \quad (11)$$

$$= \frac{y_e * z_k - y_e * z_e - y_j * z_e + y_e * z_e}{z_k - z_e} \quad (12)$$

$$= \frac{y_e * z_k - y_j * z_e}{z_k - z_e} \quad (13)$$

2.2.2 *Jittering*

Random jitter is applied to each projected point by assigning one of the eight immediate neighboring pixels (or xp, yp) to that point. [3] Its purpose is to avoid the "lattice" effect, where the points display in a strict grid-like pattern, unlike what one sees in nature. This is accomplished in the C code by creating two temporary arrays for both x and y, each of size 3:

```
yptemp[0]=yp;
yptemp[1]=yp-spacing;
yptemp[2]=yp+spacing;
```

```
xptemp[0]=xp;
xptemp[1]=xp-spacing;
xptemp[2]=xp+spacing;
```

Spacing is a random displacement from the centerpoint and can be set by the user. The actual point to be rendered will be selected by creating a value randomly of either 0, 1, or 2 by using `drand48()`, a built-in C function. The resulting value is used as an index into the arrays described above. The point rendered can be the original point that was projected or any one of eight random displacements around that point.

2.2.3 *Dithering*

Dithering provides a means of signifying magnitude. A 3 x 3 dithering matrix is used which provides for ten levels of intensity. [2] The values of the liquid water content range from 0 to 0.83 g/cm³. This range was split into 10 intervals. Thus, the value of the concentration at a pixel determines how many pixels are turned on within that 3 x 3 neighborhood. The patterns adopted in this case are as follows:

liquid water content range	pixel pattern
1. 0.0 - .08	[] [] []
2. .09 - .16	[] [*] []
3. .17 - .25	[] [* *] []
4. .26 - .33	[] [* *] [*]

5. .34 - .42

[]
[* * *]
[*]

6. .43 - .50

[*]
[* * *]
[*]

7. .51 - .59

[*]
[* * *]
[* *]

8. .60 - .67

[* *]
[* * *]
[* *]

9. .68 - .76

[* *]
[* * *]
[* * *]

10. .77 - .83

[* * *]
[* * *]
[* * *]

2.3 Results

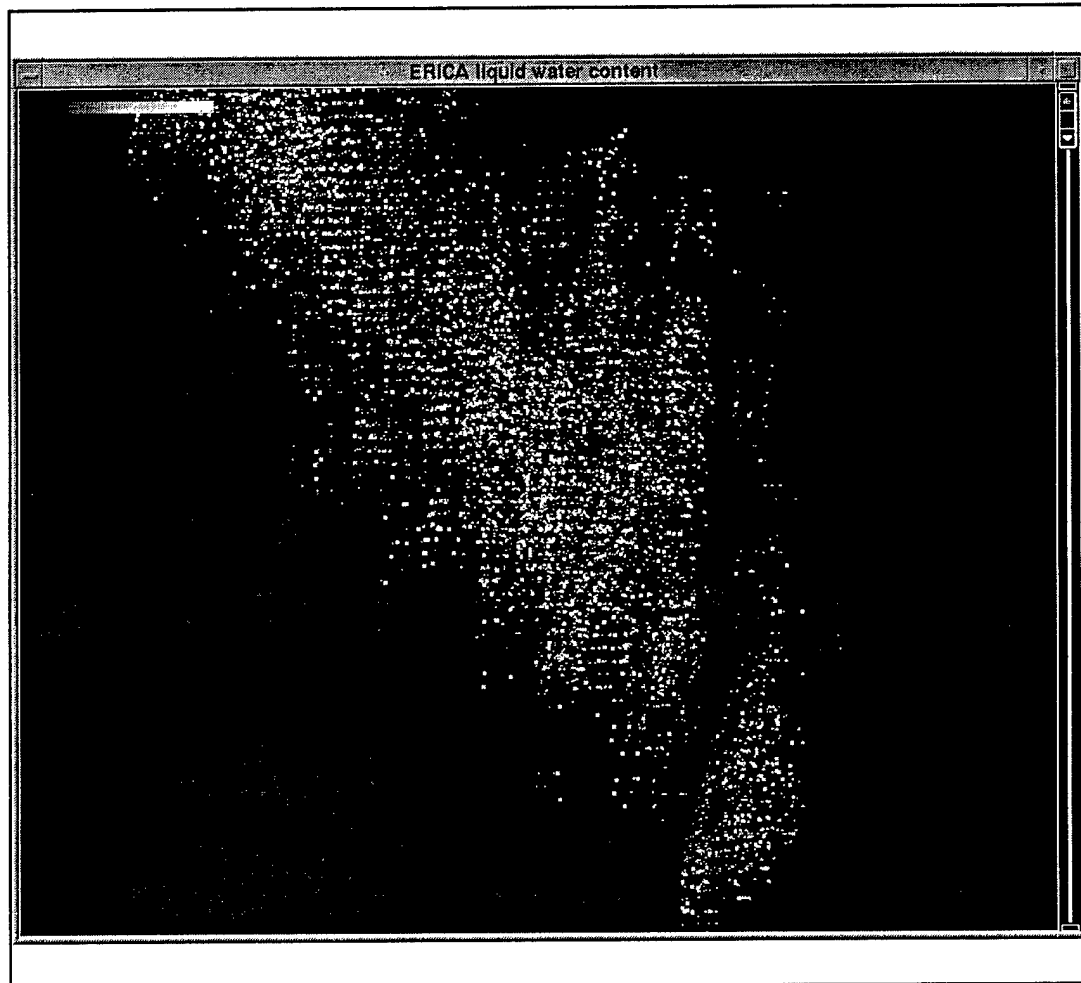


Figure 2. Three-dimensional display of ERICA liquid water content.

Displayed above is the output of the graphical rendering of the ERICA liquid water content data set as preprocessed by the LAMPS model. The lowest grid layer is easily distinguishable in the lower right hand portion of the figure slanting from southwest to northeast.

Each point in the cloud (x_i, y_j, z_k) is treated as a light source. Its corresponding perspective projection point, (x_p, y_p) , is the point that is illuminated. In this particular case, x_i ranges from 1 to 83, y_j from 1 to 53, z_k from 1 to 34. It is

assumed that the left eye and the right eye are at the same altitude and latitude and are separated by an interocular distance, e .

That is:

$$z_{EL} = z_{ER} = z_e \quad (14)$$

$$y_{EL} = y_{ER} = y_e \quad (15)$$

$$x_{ER} - x_{EL} = e \quad (16)$$

where EL refers to the left eye and ER to the right eye.

The disparity, d , is defined to be:

$$d = x_{PL} - x_{PR} \quad (17)$$

and represents the difference in x_p between the left and right eyes.

$$x_e, y_e, z_e, e$$

have been set to 15, -2100, 12, and 300, respectively, for this particular rendering. These first three values, respectively, place the viewer near the western edge, back from the cloud looking northward, and looking down.

A threshold for the minimum value of all the liquid water content array values to be displayed was set to 0.11.

XSCALE, YSCALE, and ZSCALE are parameters used when the current grid point is being projected. Their purpose is to scale the data so that it will reasonably fill the particular frame size chosen. The values used were 5, 5, and -0.3 respectively. These positive x and y values have the effect of expanding the cloud. See section 2.4 for the particular equations.

XSHIFT, YSHIFT, and ZSHIFT provide translations in the x, y, and z directions. The respective values used were 400, 1400, and 10. Section 2.4 illustrates how they are used in the equations.

The data file from the ERICA experiment contains 149,564 data points total (two points serve as bookends) with 12,368 non-zero liquid water content values. The minimum data set value is 0.0, and the maximum value is 0.83 g/cm³ of liquid water.

2.4 Outline of the C Source Code for Rendering Cloud Liquid Water Content

2.4.1 *function main()*

READ the 83 x 53 x 34 grid of liquid water content (lwc) values into a 3-d array.
CREATE a labeled window frame using xv_create().
CREATE colormap segment with xv_create().
SET frame height, width with a call to xv_set().
CREATE a conversion table for pixel values from Xview to X11.
CREATE a canvas within the frame and render the lwc values by calling xv_create() which in turn calls canvas_repaint_proc(), the procedure which does the rendering.

2.4.2 *procedure canvas_repaint_proc()*

LOOP over the 34 levels (k)

SCALE the current z value for the frame size as

$$z_k = ZSCALE * k + ZSHIFT \quad (18)$$

DETERMINE the disparity as

$$d = \frac{z_k * e}{z_k - z_e} \quad (19)$$

LOOP over the 53 columns (j)

SCALE the current y value for the frame size as

$$y_j = YSCALE * j + YSHIFT \quad (20)$$

DETERMINE where the y point will project for rendering as

$$y_p = \frac{(y_e * z_k) - (y_j * z_e)}{(z_k - z_e)} \quad (21)$$

LOOP over the 83 rows (i)

SCALE the current x value as

$$x_i = XSCALE * i + XSHIFT \quad (22)$$

DETERMINE where x point will project for left eye as

$$x_{PL} = \frac{(x_e * z_k) - (x_i * z_e)}{(z_k - z_e)} \quad (23)$$

DETERMINE where x point will project for right eye as

$$x_{PR} = (float) x_{PL} - d + 0.5 \quad (24)$$

JITTER the current data point.

DRAW the appropriate dither pattern given the value of the current data point.

END LOOP

END LOOP

END LOOP

3. Conclusions

A fairly realistic static depiction of a cloud was produced from the cloud liquid water content data. A time-lapse sequence depiction of a cloud would capture its dynamic nature, and this static depiction is a good first step toward that goal. Further experimentation with different dithering matrices and different perspectives would be beneficial to see if any improvements could be made to the system.

4. Recommendations

A conversion from Xview to Motif should be carried out, since Motif is the government standard used. It is also unclear if Sun will continue to support Xview.

The author has had recent discussions with Professor McCoy on ways to make the cloud rendering more realistic. One method discussed, would render cubes rather than just pixels. The color for a particular cube face would be a function of the amount of water droplets between the reflecting cube and the eye, and the magnitude of the liquid water content at that point. A light source could also be added, which would involve taking shadows into account.

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Acronyms and Abbreviations

ERICA	Experiment on Rapidly Intensifying Cyclones over the Atlantic
LAMPS	Limited Area and Mesoscale Prediction System

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